

SIGNATURES OF ASYMMETRY IN SN IIP

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Collaboration on SN2004dj

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1. Introduction (87a, 99em)
2. Asymmetry in H α of SN 2004dj (obs.& mod.)
3. Polarization model for SN 2004dj
4. Conclusion

before SN1987A

'Explosion' of CCSN implying asymmetry:

Kardashev (1964), Bisnovatyi-Kogan (1970): MR explosion

Colgate&Petschek (1980): \mathbf{v} : Large scale \mathbf{v} -convection

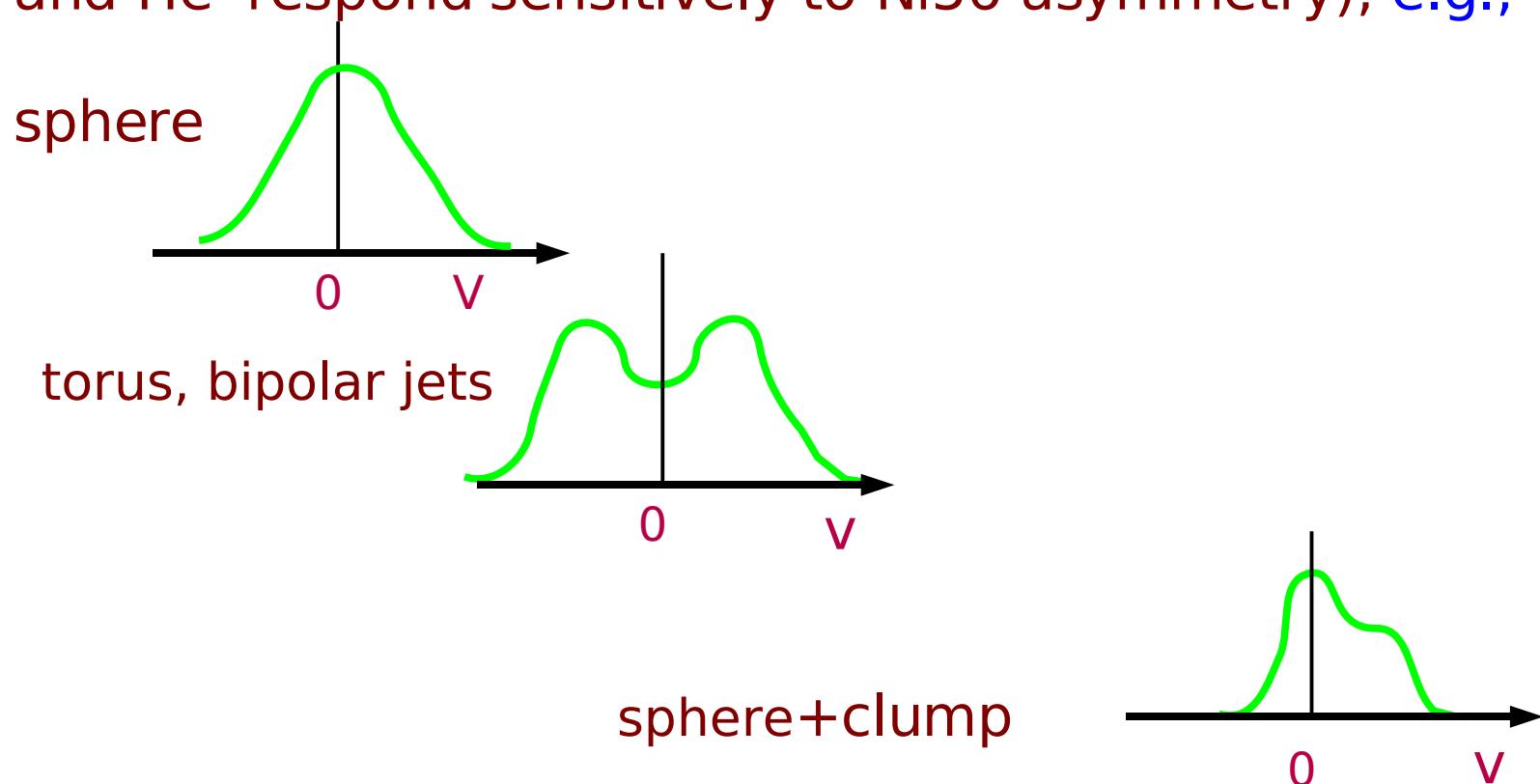
Observational manifestations of asymmetry:

LeBlanc&Wilson (1970): Ω & $\mathbf{B} \Rightarrow$ bipolar jets

Bodenheimer& Woosley (1983): $\Omega \Rightarrow$ equatorial ejecta

Asymmetry toolkit

1. Direct imaging (SN 1987A)
2. Polarization (Thomson scattering, resonance scattering)
3. Deviations of emission line profile from the symmetry (note, H and He respond sensitively to Ni56 asymmetry), e.g.,

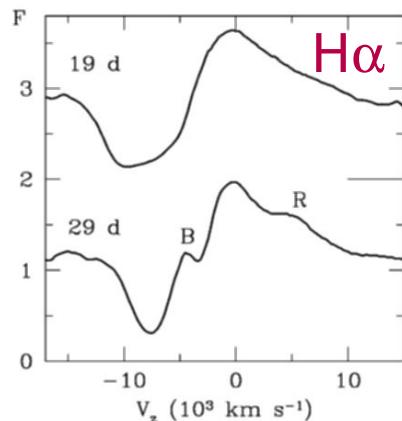


SN 1987A: polarization & line asymmetry

Red component of Pa α (Larson et al 1987)

Bochum event (Hanuschik&Dachs 1987)

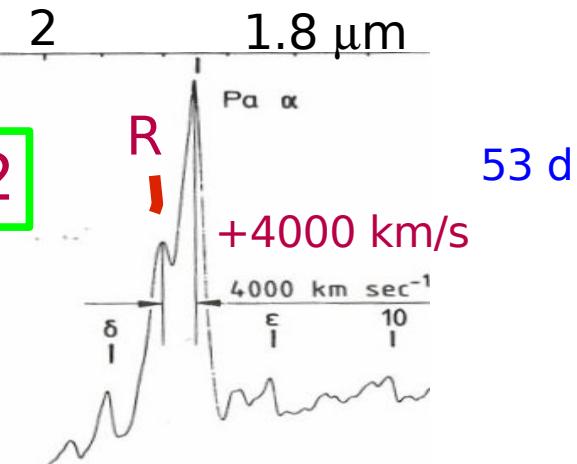
1



Does Bochum event imply bipolar Ni-56 jets?
No. It does not.

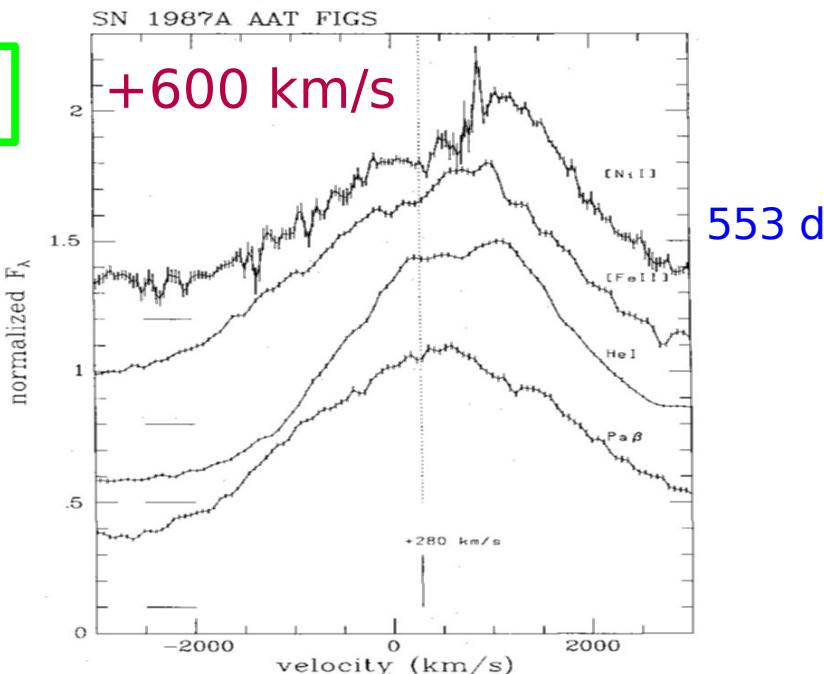
2 1.8 μm

2



Redshift of nebular lines (Meikle et al 1990)

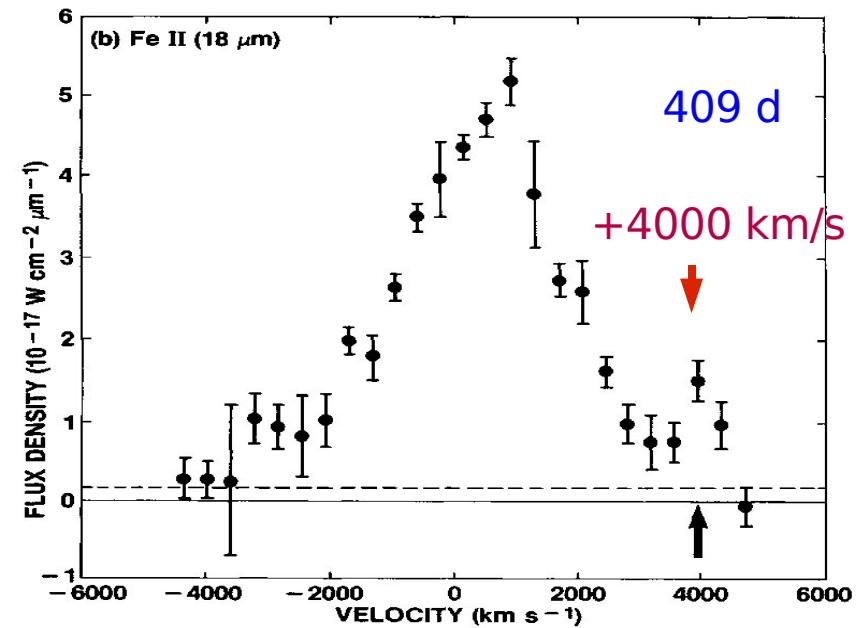
3



553 d

Red component of Fell lines (Haas et al 1990)

4



409 d

SN 1987A : asymmetry ambivalence

1. Line redshift and red component:

one-sided Ni56 ejecta in a spherical envelope

2. HST images:

bipolar Ni56 jet (Wang et al. 2002)

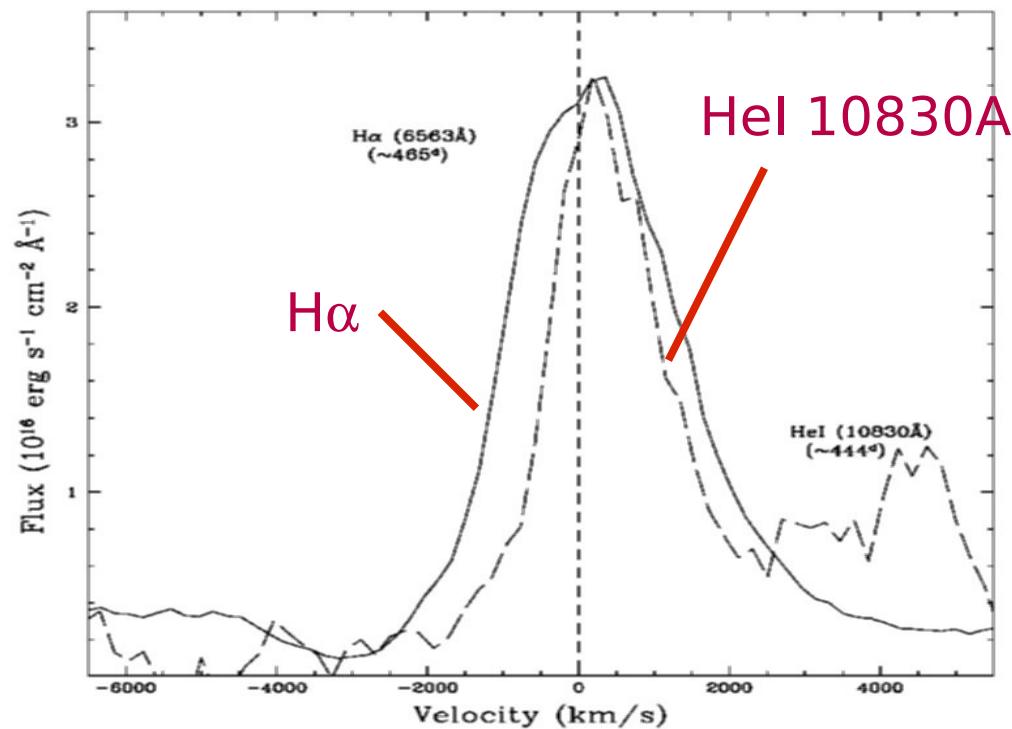
Consensus picture:

Bipolar asymmetric Ni56 ejecta

SN 1999em (=normal type IIP):

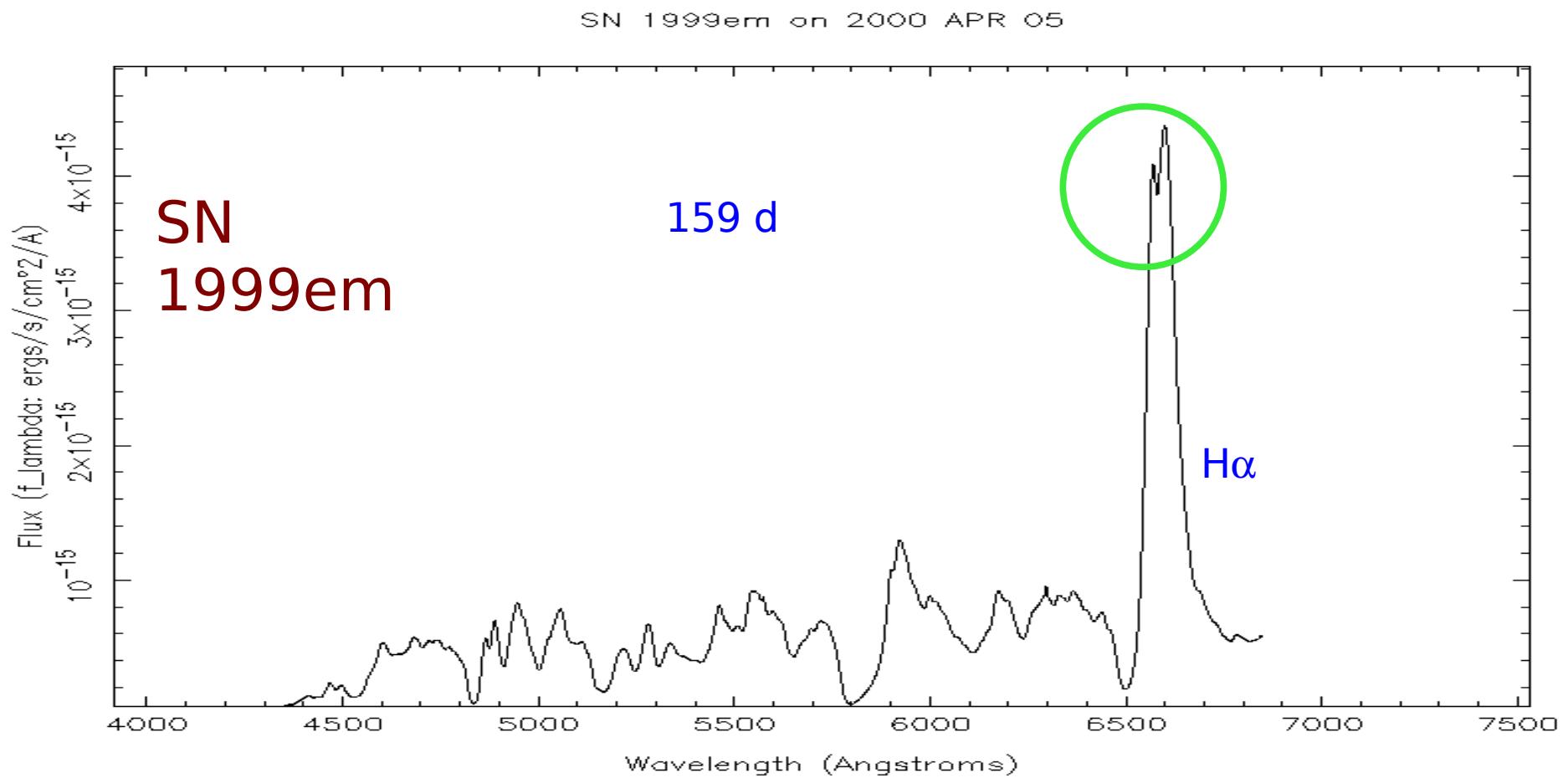
Polarization (Leonard 2001)

Line redshift (400 km/s) => asymmetric Ni56 (Elmhamdi et al. 2003)



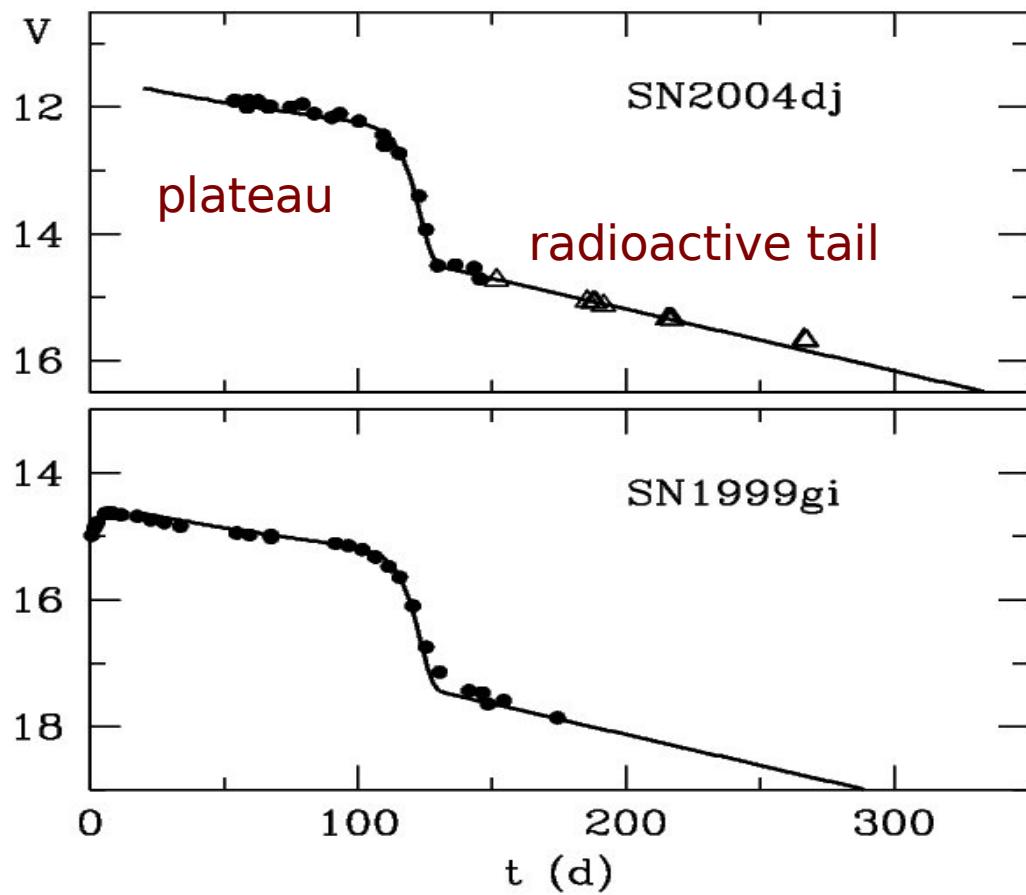
Spectral evidence for the asymmetric bipolar Ni56 jets:

(spectrum: Leonard et al.)

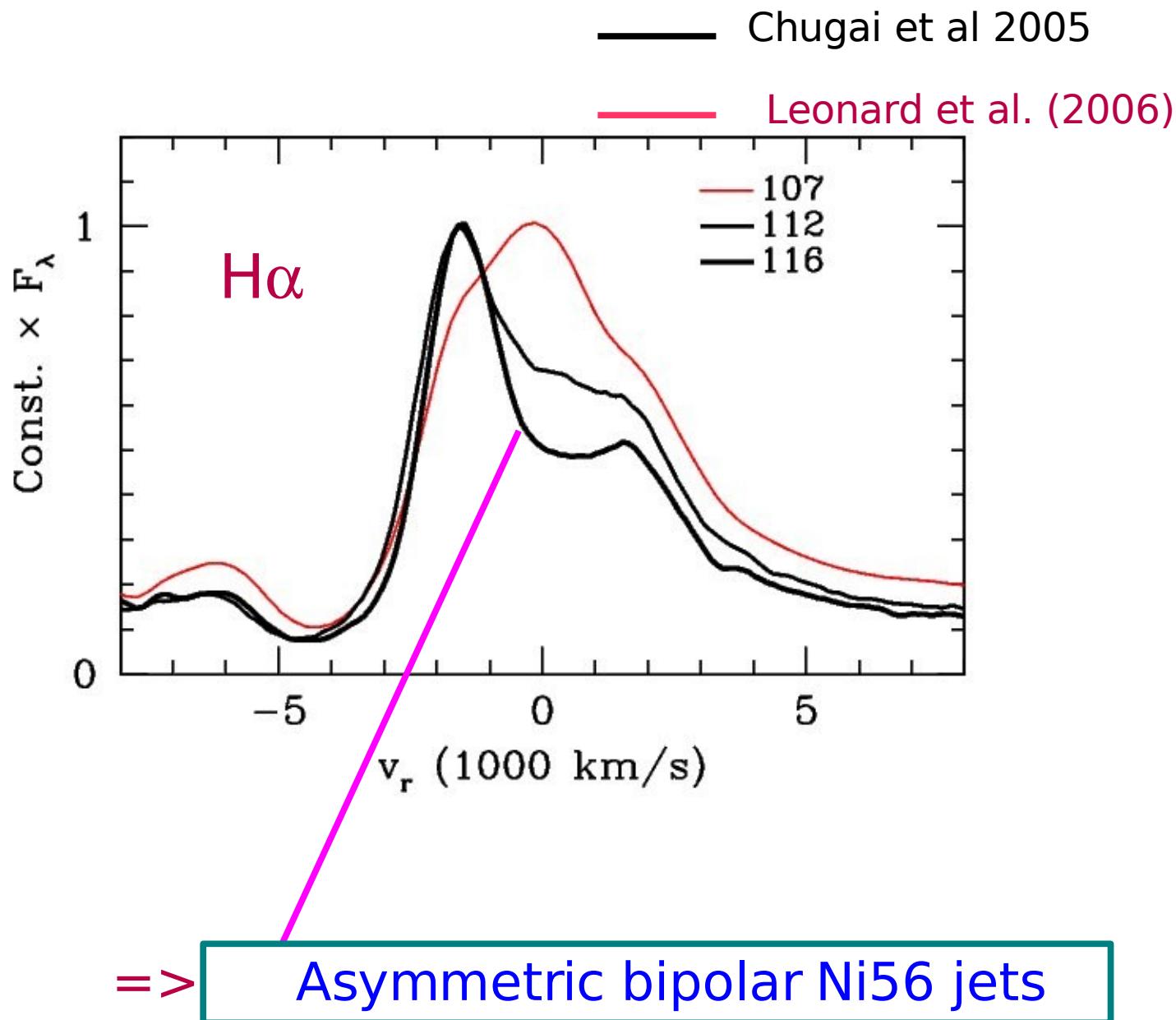


SN 2004dj (normal IIP)

(Nakano et al. 2004), NGC 2403, D=3.13 Mpc

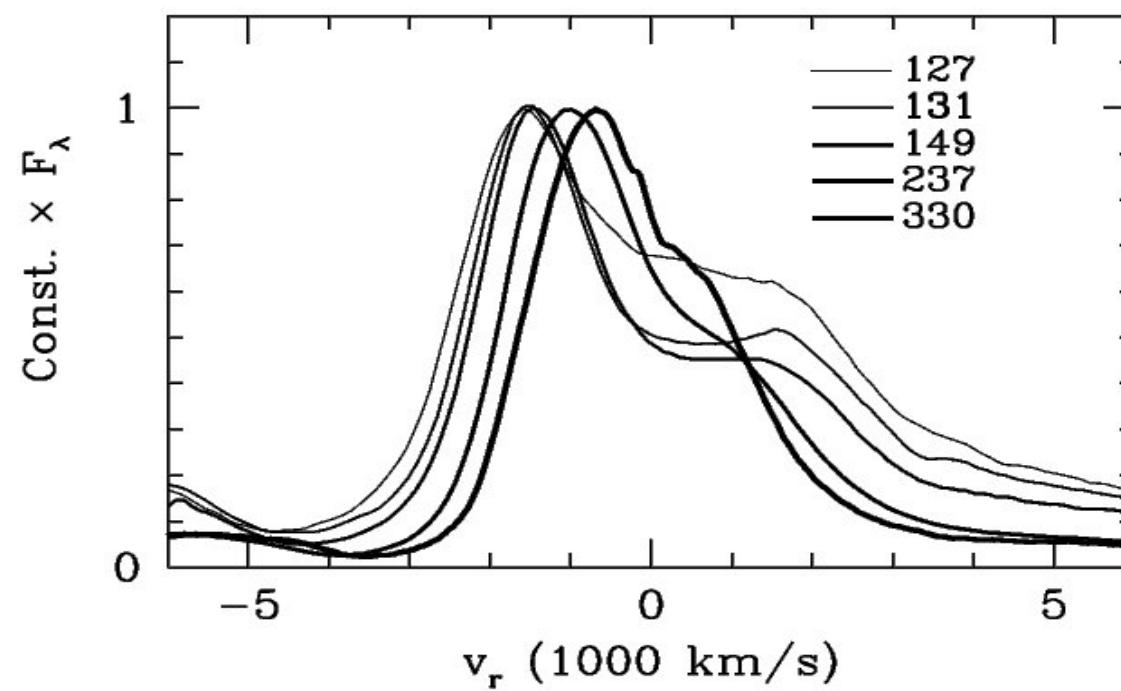


SN 2004dj: emergence of line asymmetry at the nebular phase



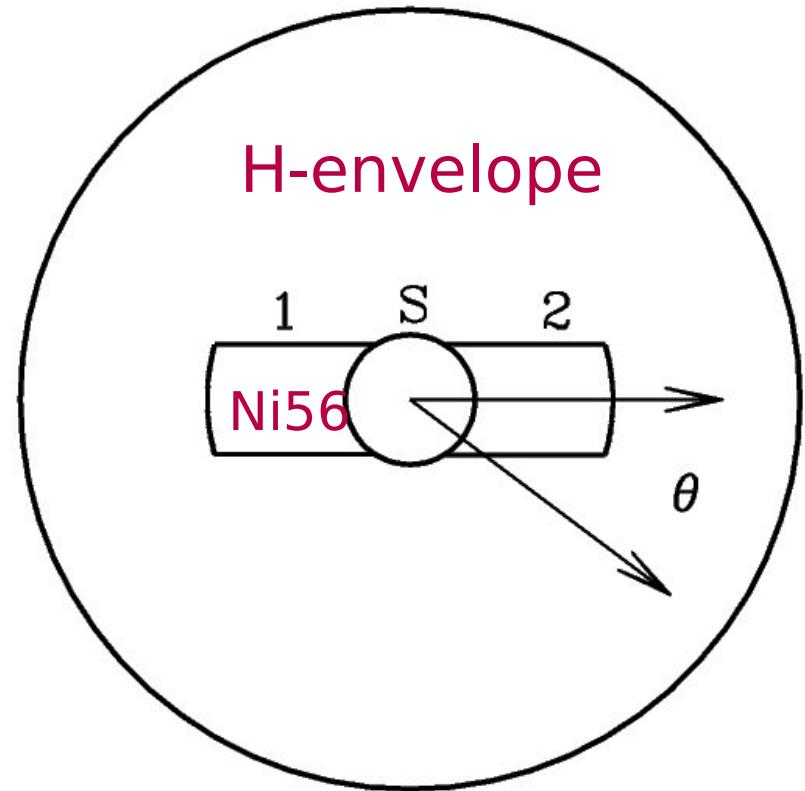
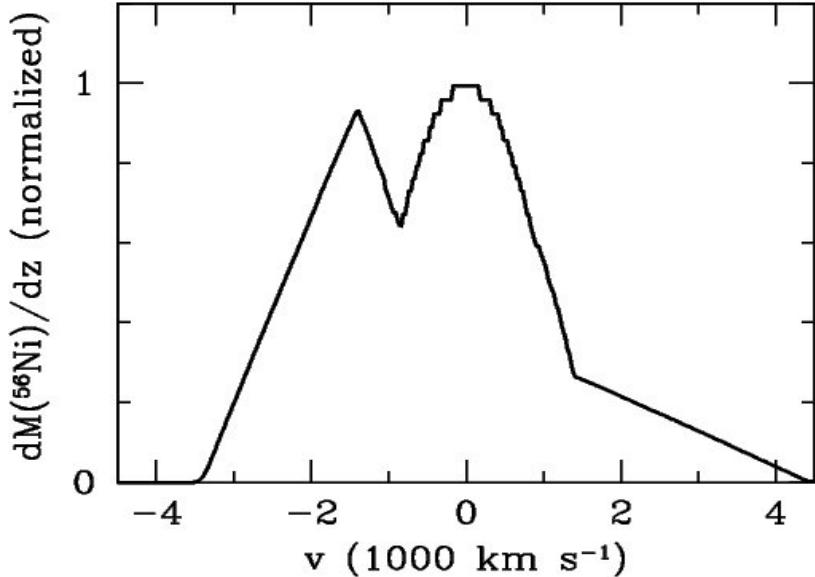
SN 2004dj : H α evolution at the nebular epoch

=> asymmetric bipolar Ni56 jets in symmetric H envelope?



Model

Linear Ni56 mass density, e.g.,



Parameters: $M=15M_{\text{sun}}$, $E=1.3 \text{ bethe}$, $\rho(v)=C \exp(-v/v_0)$,

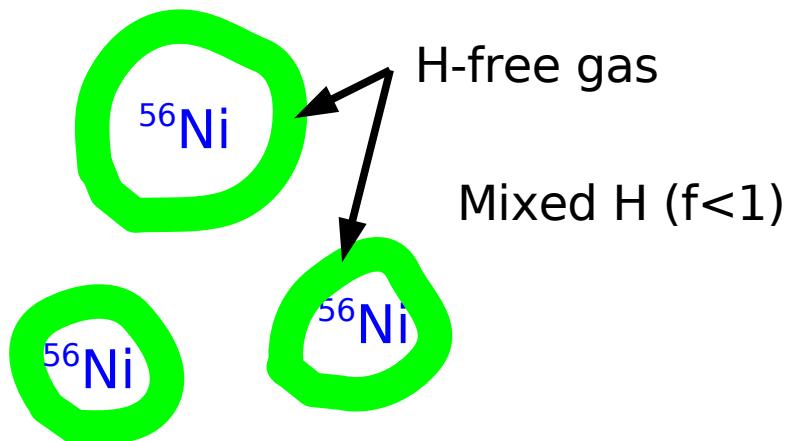
v [3], $M(\text{Ni})$ [2], θ

- + Ni56 should be coated by H-free cocoons

[Similar problem in SN 1987A for CO emission at 100 d:
energy input reduction factor (Liu&Dalgarno 1995)]

Model of central Ni56 and H mixing:

Parameters:

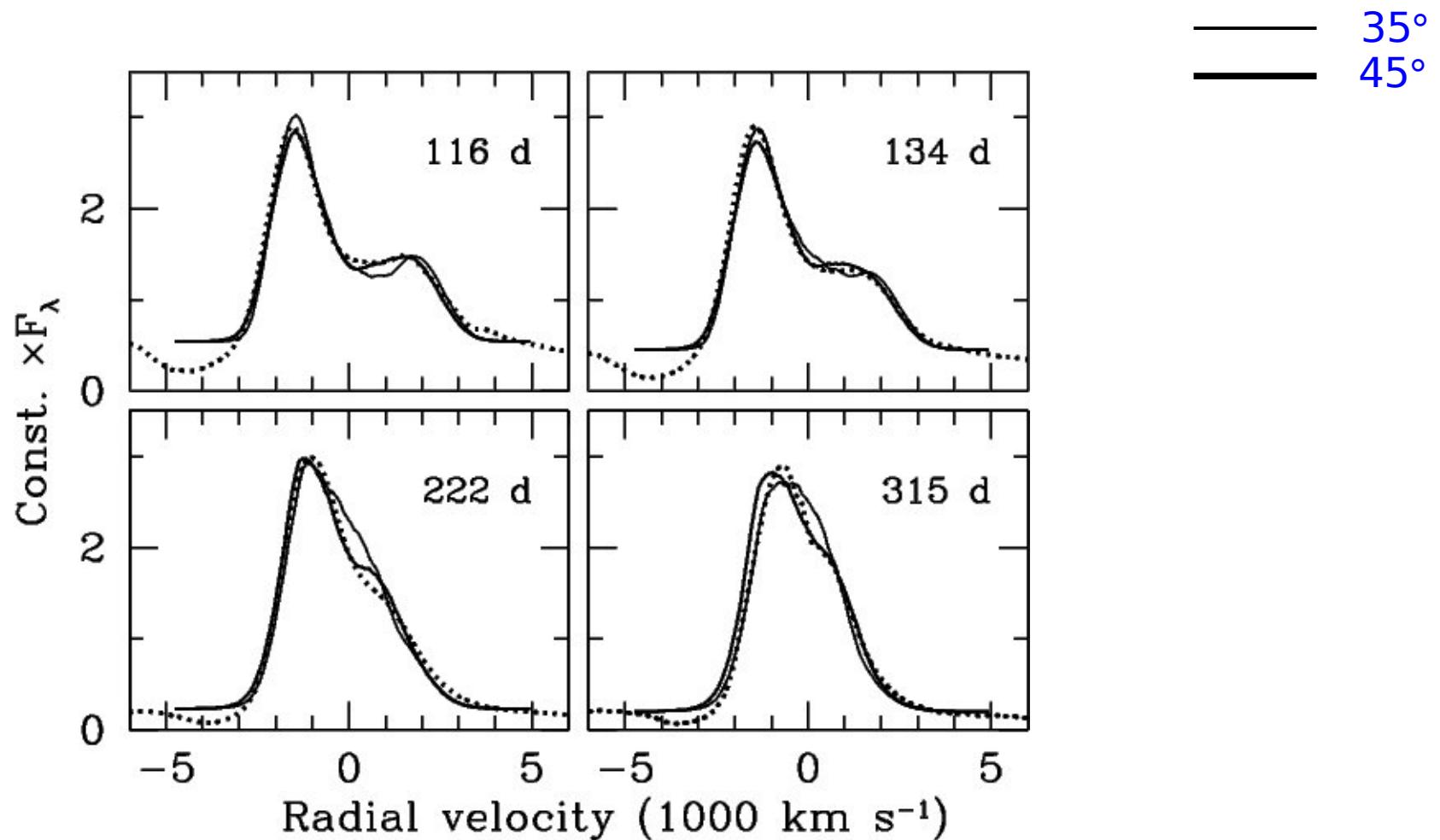


$$S/(4\pi(v_s t)^2) = 2$$

$$M(\text{cocoons}) = 1 M_{\text{sun}}$$

$$f(H) = 0.4$$

SN 2004dj, H α profile: Model against observations (dots)



Parameters of Ni56 distribution

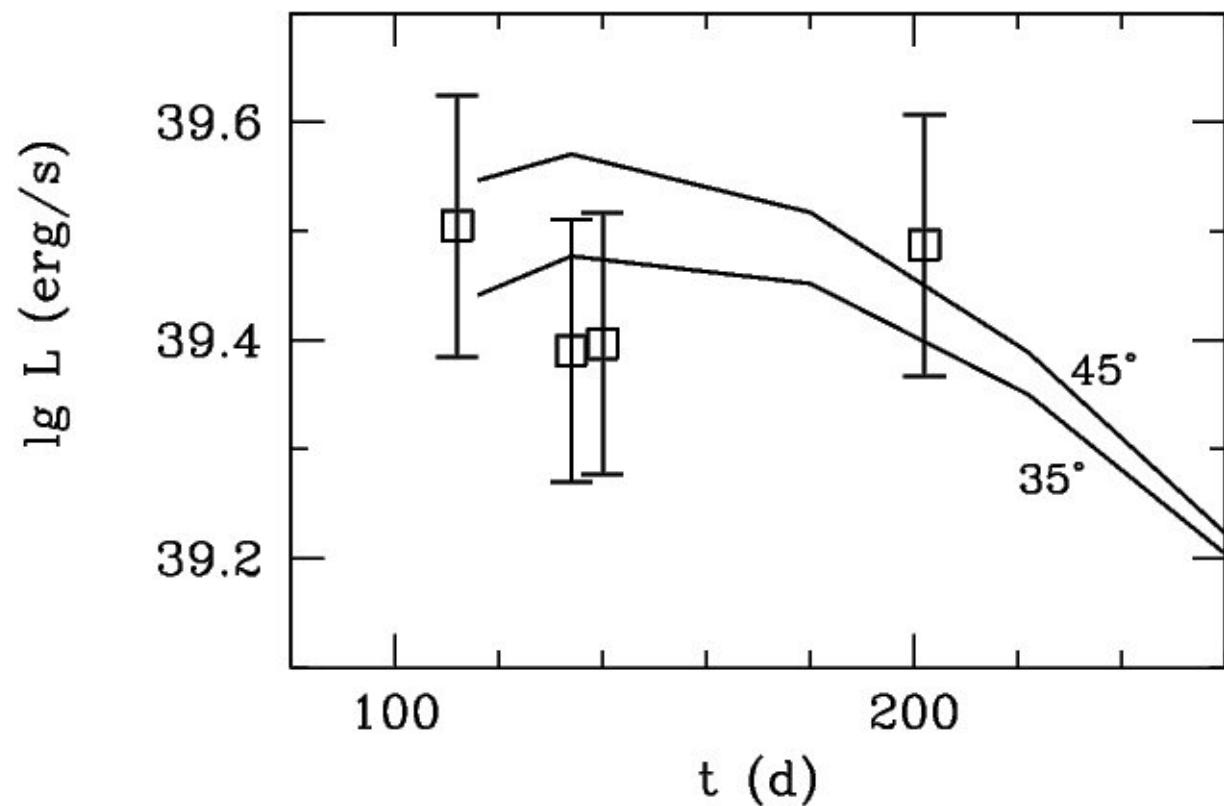
<i>i</i>	<i>v_sym</i>	<i>v_1</i> (km/s)	<i>v_2</i>	<i>M_sym</i>	<i>M_1</i> (<i>M_sun</i>)	<i>M_2</i>	<i>M_1/M_2</i>
35°	1200	3000	4000	0.012	0.0056	0.0024	2.3
45°	1400	3500	4500	0.0105	0.0068	0.0027	2.5

$$35^\circ \quad (Mv)_1 / (Mv)_2 = 1.75$$

$$45^\circ \quad (Mv)_1 / (Mv)_2 = 1.96$$

The model against the observed H α luminosity

[M(Ni56)=0.02M_sun from the light curve]

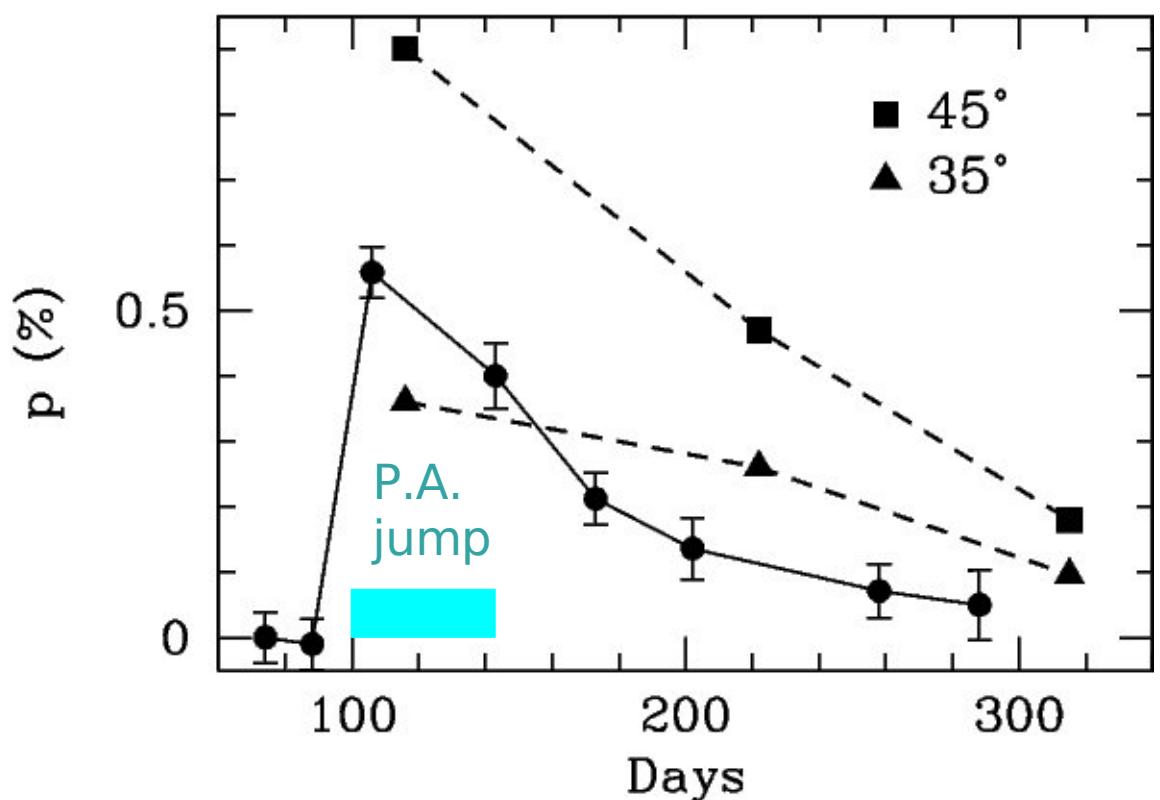


Asymmetric bipolar Ni56 jets vs. polarization

Polarization model:

- * the same $n_e(z,p)$
- * emissivity \propto deposition
- * only Thomson scattering

- * General agreement (amplitude and decay).
- * Although not in detail : Line scattering? Non-axial jets?
H α model?
- * P.A. jump: 1. non-axial jet (Leonard et al. 2006)
2. macroscopic mixing -> spotty photosphere



Data:
Leonard et al (2006)

Conclusions:

1. H α of SN 2004dj indicates the asymmetric bipolar Ni56 jets
2. Asymmetric bipolar Ni56 jets seem to be the generic to SNe IIP (87A, 99em, 04dj, ...)

Contemplations

Ni56 bipolar jets in IIPs:

Ω may be relevant for SN 1987A
but what about IIP in general?

Violation of the point symmetry:

symmetric bipolar jets modified by propagation
or imprinted explosion asymmetry, e.g.,
 $l=1$ mode of v -convection (Herant et al. 1992,
Janka et al. 2005)